Utility of dynamic computed tomography angiography in the preoperative evaluation of skull base tumors

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OBJECT The anatomical complexity of skull base tumors mandates detailed preoperative planning for safe resection. In particular, the location of critical vascular and bony structures can influence the surgical approach. Traditional methods, such as MRI, MR angiography and/or venography (MRA/MRV), CT angiography and/or venography (CTA/CTV), and digital subtraction angiography, each have their limitations. One alternative that combines the benefits of both detailed anatomy compatible with intraoperative image guidance and visualization of the vascular flow is the 320−detector row dynamic volume CTA/CTV. The authors investigated this technique’s impact on the surgical approach used in a series of complex intracranial tumors.

METHODS All patients with complex intracranial tumors who had undergone preoperative dynamic CTA/CTV as well as MRI in the period from July 2010 to June 2012 were retrospectively reviewed. Those in whom only routine CTA/CTV sequences had been obtained were excluded. Clinical records, including imaging studies, operative reports, and hospital course, were reviewed. Ease in detecting specific major arterial and venous tributaries using dynamic CTA/CTV was graded for each case. Furthermore, 2 skull base neurosurgeons projected a desired surgical approach for each tumor based on MRI studies, independent of the CTA/CTV sequences. The projected approach was then compared with the ultimately chosen surgical approach to determine whether preoperative awareness of vasculature patterns altered the actual operative approach.

RESULTS Sixty-four patients were eligible for analysis. Dynamic CTA/CTV successfully demonstrated circle of Willis arteries, major draining sinuses, and deep internal venous drainage in all cases examined. The superior petrosal sinus, vein of Labbé, tentorial veins, and middle fossa veins were also identified in a majority of cases, which played an important role in preoperative planning. Visualization of critical vascular—especially venous—anatomy influenced the surgical approach in 39% (25 of 64) of the cases.

CONCLUSIONS Dynamic CTA/CTV has been applied to few neurosurgical disease pathologies to date. This noninvasive technology offers insight into vascular flow patterns as well as 3D anatomical relationships and provides thin-cut sequences for intraoperative navigation. The authors propose dynamic CTA as an addition to the preoperative planning for complex skull base tumors.

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KEY WORDS skull base tumors; skull base surgery; dynamic CT angiography; preoperative surgical planning; venous anatomy

SAFE skull base surgery is predicated on knowledge of the relevant vascular anatomy. The precise anatomical configuration of temporal bridging veins in the petrosal approach and carotid tributaries in anterior or middle fossa pathologies as well as the determination of sagittal sinus patency in falcine masses, for instance, can all influence surgical exposure. Unintentional sacrifice of critical bridging vessels can lead to infarction and significant morbidity; therefore, optimizing visualization of such bridging vessels preoperatively is crucial in skull base surgery.

Preoperative imaging has traditionally included MRI, MR angiography and/or venography (MRA/MRV), CT angiography and/or venography (CTA/CTV), and digital

ABBREVIATIONS CTA = CT angiography; CTDIvol = volumetric CT dose index; CTV = CT venography; DLP = dose length product; DSA = digital subtraction angiography; MRA = MR angiography; MRV = MR venography.

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* Drs. Bi and Brown contributed equally to this work. Drs. Mukundan and Dunn share senior authorship of this work.
subtraction angiography (DSA). Each modality has its benefits and limitations. Magnetic resonance imaging/MRA/MRV allow delineation of tumor structure while affording adequate visualization of larger-caliber vessels. Conventional CTA/CTV offers higher sensitivity and specificity in detecting vascular anatomy than MR-based techniques, but these imaging techniques become more limited in detecting small structures near the skull base given interference from adjacent osseous structures. They also offer a static view of the vascular anatomy. Digital subtraction angiography has traditionally represented the gold standard for elucidating vascular anatomy, but it also carries the associated neurovascular risks of stroke and arterial dissection, as well as the cost and time limitations of an invasive procedure. An ideal alternative would combine visualization of the vascular flow from arterial to venous phases, detection of fine-caliber vessels, as well as demarcation of tumor and cranial anatomy in a safe and rapid manner, while also allowing this information to be incorporated into image guidance platforms. We investigated 320-detector row dynamic volume CTA/CTV as an effective alternative in elucidating critical vascular, especially venous, anatomy, and we evaluated its impact on surgical approach in complex intracranial tumors.

Methods

Patient Identification

All patients with complex intracranial tumors who had undergone dynamic CTA/CTV as well as MRI prior to surgery in the period from July 2010 to June 2012 were retrospectively reviewed. Patients were excluded if only routine CTA/CTV sequences had been obtained. Clinical records, including imaging studies, operative reports, and hospital course, were reviewed for the cohort meeting the study criteria.

Image Acquisition

Dynamic CTA/CTV images were procured using a 320-detector row dynamic volume CT scanner (Aquilion One, Toshiba Medical Systems) while applying the following scanning protocol (Fig. 1A). Patients undergo a helical acquisition high-resolution nonenhanced CT scan of the head with 0.5-mm slice thicknesses before the administration of 75 ml of intravenous isosmolar iodinated contrast (iopamidol injection 76%, Isovue-370, Bracco Diagnostics). Serial dynamic volume acquisitions ensue with the patient's head centered in the CT gantry and the collection of 320-slice volume acquisitions with 0.5-mm slice thicknesses. At 7–8 seconds postinjection, we obtain a volume acquisition that is used as a “mask acquisition” analogous to that obtained during DSA. The volumetric data from the mask is subtracted from the volume data subsequently acquired, essentially providing a 3D volumetric subtraction angiogram to obtain vessel-specific images. An early arterial phase at 11–18 seconds, a midarterial phase at 20–28.5 seconds, and a late arterial phase at 30–37 seconds after contrast injection are acquired with serial pulses of 1 second “on time” followed by 1 second “off time,” before acquisition of a venous phase at 40–61 seconds postinjection.

Postprocessing software projects the dynamic time-reolved imaging data into conventional angiographic imaging planes with selective display of opacified vessels from the right and left circulations, as well as 3D volume-rendered vessel imaging. We adopted a convention of presenting vascular data for the left hemisphere with the patient's nose pointing toward the left and, conversely, for the right hemisphere with the patient's nose pointing toward the right, to facilitate user interpretation. The standard CTA sequence was fused with MRI studies for image guidance during all cases.

Data Analysis

A predetermined set of arterial and venous structures was selected for identification on dynamic CTA/CTV in all cases. Arteries examined in each case included the anterior cerebral artery, middle cerebral artery, posterior cerebral artery, anterior communicating artery, posterior communicating artery, basilar artery, vertebral artery, and ophthalmic artery. Venous structures examined in each case included the superior sagittal sinus, inferior sagittal sinus, transverse sinus, sigmoid sinus, jugular bulb, straight sinus, vein of Galen, internal cerebral veins, basal vein of Rosenthal, vein of Labbé, cavernous sinus, superior petrosal sinus, tentorial veins, veins coursing along the middle fossa floor, and prominent veins coursing along the sylvian fissure. Major arterial and venous tributaries were characterized as not seen, partially seen, or clearly seen, based on reviews of dynamic CTA/CTV by at least 2 individuals. Furthermore, 2 skull base neurosurgeons (O.A., L.F.D.) compared the desired MRI-based surgical approach for each tumor with the ultimately chosen surgical approach to determine whether preoperative awareness of the vasculature supply and drainage patterns altered the surgical approach performed.

Radiation Dose Considerations

Dose comparisons among multiple modalities can be best achieved with the effective dose (S), which is derived by applying standardized coefficients (k-factors) for different organs to the dose length product (DLP) output when a scan protocol is performed. Effective dose is calculated using the following equations: DLP (mGy-cm) = CTDIvol (mGy) × scan length (cm), and S (mSv) = DLP × k, where CTDIvol is the volumetric CT dose index given for each scan protocol and k = 0.0023 for head CT. Note that while effective dose is a nonstandard way of expressing dose in CT applications, it is useful for comparisons of dose across modalities—in this case, for comparing CTA/CTV to catheter angiography.

Results

Patient Demographics

Sixty-four patients (31 males and 33 females, with a mean age of 50 years) with complex intracranial tumors underwent dynamic CTA/CTV and MRI prior to surgery during the study period (Table 1). The most frequent pathologies for which dynamic CTA/CTV was performed were meningioma (31 patients [48%]), schwannoma (10 patients [16%]), chordoma or chordosarcoma (7 patients [11%]), and epidermoid or dermoid cyst (6 patients [9%]).
Vascular Visualization

Dynamic CTA/CTV successfully demonstrated the circle of Willis arteries, cavernous sinus, transverse sinus, sigmoid sinus, internal jugular vein, straight sinus, vein of Galen, internal cerebral veins, and basal vein of Rosenthal in all cases (Table 2, Fig. 2, and Video 1).

VIDEO 1. Serial sequence of representative dynamic CTA/CTV, in sagittal and axial views. Copyright Ian F. Dunn. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

The vein of Labbé could be easily identified in all but 1 case in which a dominant lateral temporal vein was less apparent among the multiple tributaries seen. The superior petrosal sinus was identified in 53 (83%) of 64 patients. A prominent draining vein coursing along the middle fossa was seen in 49 (77%) of 64 cases. Tentorial draining veins, sylvian veins, and the inferior sagittal sinus were identified in approximately half of the cases.

Impact on Surgical Approach

Visualization of critical vascular, especially venous, anatomy influenced surgical approach in 39% (25 of 64) of cases. Reasons for imaging-influenced adjustment of an approach included the presence of major veins traversing the tentorium, discouraging a posterior approach in which the tentorium would be sectioned; patency of major draining sinuses encompassed by tumor, dictating the use of a venous graft versus the ability to sacrifice the sinus; and location of major frontal veins limiting craniotomy boundaries (Table 3). Three select cases are illustrated below.

Radiation Dose Considerations

The dynamic scan protocol yields a CTDIvol of 268.3 mGy and DLP of 4409 mGy-cm, producing an effective dose of 10.14 mSv. The dynamic component of the scan accounts for an effective dose of 7.46 mSv. For the sake of comparison, at our institution, a typical standard head CTA study consisting of a sequential noncontrast scan of the head, CTA, and delayed postcontrast helical scan produces a DLP of 2414 mGy-cm and an effective dose of 5.55 mSv (Table 4). The strength of dynamic CTA to produce high-resolution venous vascular data relies on a time-resolved volumetric acquisition sequence, which accounts for the increased dose compared with that used in a standard CTA/CTV protocol.
A 51-year-old woman presented with unilateral ptosis, and subsequent workup revealed a left petroclival meningioma on MRI (Fig. 3A–B). Tumor originated medial to the trigeminal nerve, closely juxtaposed to it as well as to the abducens, facial, and auditory nerves, and extending anteriorly to Meckel’s cave. One potential surgical option involved a posterior petrosal approach with sectioning of the tentorium to allow access to the full extent of the tumor. However, dynamic CTA/CTV revealed a dominant left vein of Labbé coursing along the tentorium, prompting a transmastoid retrosigmoid approach to the posterior fossa with partial mastoidectomy and sparing of the tentorium (Fig. 3C–D).

Case 2

A 52-year-old woman had a recurrent left petrous apex meningioma on serial MRI (Fig. 4A–B). Preoperative dynamic CTA/CTV revealed a prominent vein coursing from the sylvian vein across the tentorium to the transverse sinus (Fig. 4C–D). Given this venous drainage pattern, a preauricular middle fossa approach was chosen along with drilling of the petrous apex for resection of the tumor.

Case 3

A 37-year-old woman presented with progressive right oculomotor palsy and was found to have a right sphenopetrous meningioma on MRI (Fig. 5A–B). Dynamic CTA/CTV revealed a dominant right vein of Labbé that coursed superior to the tentorium (Fig. 5C–D). Given the separate course of the vein of Labbé from the tentorium, a combined anterior and posterior petrosal approach was pursued for tumor resection with safe incision of the tentorium.

Discussion

Skull base tumors lead to morbidity in their growth as well as their resection because of an intimate relationship with surrounding cranial nerves, vasculature, and other critical anatomical structures. In particular, venous anatomy surrounding the temporal lobe and tentorium frequently influences the surgical window within which skull base tumors are approached. Multiple cadaveric studies
Dynamic CTA in skull base surgery

have been performed to improve understanding of the anatomy of the bridging veins and sinuses as well as safe manipulation of these structures during surgery. Safe application of such knowledge in patients calls for efficient and sensitive imaging modalities.

Vascular Detection Considerations

The most common imaging modalities for the visualization of tumor and vascular structures include MRI/MRA/MRV, CT/CTA/CTV, and DSA. The sensitivity and specificity of CTA in comparison with MRA and DSA have been most extensively studied in intracranial atherosclerotic disease. In this population, CTA provides significantly higher specificity and sensitivity than MRA, approaching that of DSA for large intracranial vessels, and offers high interoperator reliability in interpretation. Traditional helical CTA, even when combined with a delayed venous phase to offer CTV, fails to provide vascular flow data.

Recently, dynamic 320-detector row CTA/CTV, also known as 4D CTA, was investigated in a few neurosurgical diseases, including aneurysm and dural arteriovenous fistula, but not in neurooncological pathologies to date. Dynamic CTA provides a time-resolved, phase-resolved volumetric examination with output comparable to that of standard catheter cerebrovascular angiography but without the associated risks. Furthermore, it offers high fidelity in detecting the circle of Willis arteries and major draining sinuses, as demonstrated across our patient population. The minimal crossover between arterial and venous phases limits false interpretation of early draining vessels to identify critical venous structures with higher fidelity than standard CTA/CTV. The high resolution of acquired images can also be used for intraoperative navigation, either independently or fused with MRI sequences of tumors.

Impact on Surgical Approach

The most frequent application of dynamic CTA/CTV data in influencing the surgical approach in our study involves the presence of bridging temporal and tentorial veins and the decision to preserve the tentorium in either an anterior or posterior petrosal approach. While more than one-third of the surgical approaches were believed to be affected by preoperative vascular imaging, in 1 of the 64 cases, a tentorial vein extending into an anterior sylvian vein was not seen during preoperative evaluation of a petroclival meningioma. Although a combined petrosal approach was prepared for, intraoperative finding of this vein led to a preauricular subtemporal middle fossa approach along with anterior petrosectomy ultimately. Because of the soft texture encountered within the tumor, the meningioma was successfully resected via an anterior approach alone. Although draining veins along the tentorium were demonstrated on imaging in only approximately half of the cases, this was the only case in which a bridging vein with significant consequence was visualized intraoperatively but not preoperatively. However, the tentorial vein was recognized on a repeat review of imaging after surgery, attesting to the sensitivity of dynamic CTA/CTV and its place as an important addition to the preoperative planning of complex intracranial and skull base tumors.

We have refined the manner in which dynamic images are used. All images are reviewed in conjunction with a neuroradiologist prior to surgery. Relevant vascular structures include those encountered during the surgical approach, such as crossing veins during a craniotomy and tentorial sectioning, and vessels that may be altered by the tumor itself through encasement or narrowing of its caliber. The most commonly noted finding is a prominent vein that courses through a standard approach trajectory. In these cases, attempts are made to preserve or avoid such a structure through modifications of the surgical approach. Encapsulation of major vessels, without full occlusion, prompts additional precautions during tumor dissection. Relevant bony anatomy may also be reviewed and is incorporated into the image guidance platform. These experiences have led to an institutional practice of ob-
taining routine preoperative dynamic CTA/CTV studies in conjunction with MR images for the majority of skull base lesions. This allows a large sampling of our skull base patient cohort for this study and helps to minimize the selection bias that accompanies the acquisition of dynamic CTA/CTV studies only in patients in whom there is a preexisting concern about vascular anatomy. In addition, the ability to apply the high-resolution CTA sequence for image guidance, either by itself or fused with an MRI sequence, provides another advantage during surgeries.

**Radiation Dose Considerations**

The radiation dose delivered to the patient is an important consideration when comparing techniques. In

**TABLE 3. Summary of cases in which preoperative evaluation of vascular structures influenced the operative approach**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Tumor Type, Location</th>
<th>Influential Vascular Anatomy</th>
<th>Surgical Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>57, M</td>
<td>Chordoma, clival</td>
<td>Small ICA branch enmeshed in tumor</td>
<td>Extension of transsphenoidal approach</td>
</tr>
<tr>
<td>2</td>
<td>59, M</td>
<td>Chordoma, clival</td>
<td>Dominant ipsilateral IJV w/ prominent bulb, atertic central transverse/sigmoid sinus</td>
<td>Heightened awareness &amp; avoidance of any venous injury during approach</td>
</tr>
<tr>
<td>3</td>
<td>66, M</td>
<td>Craniohypophyseoma, suprasellar</td>
<td>Tentorial v. feeding into v. of Labbé</td>
<td>Altered middle fossa approach to presigmoid petrosal approach</td>
</tr>
<tr>
<td>4</td>
<td>20, F</td>
<td>Dermoid cyst, sellar/suprasellar</td>
<td>Hypoplastic rt A, segment</td>
<td>Planning of surgical approach given prior visual loss</td>
</tr>
<tr>
<td>5</td>
<td>53, M</td>
<td>Epidermoid, pst fossa</td>
<td>Tentorial v.</td>
<td>Expansion of pst petrosal to additional ant petrosal approach to avoid cutting tentorium</td>
</tr>
<tr>
<td>6</td>
<td>61, M</td>
<td>Epidermoid, pst fossa</td>
<td>Dominant v. of Labbé, ipsilateral atretic transverse/sigmoid sinus</td>
<td>Influenced transmastoid retrosigmoid over presigmoid approach</td>
</tr>
<tr>
<td>7</td>
<td>34, F</td>
<td>Epidermoid, pst fossa</td>
<td>Tentorial v. &amp; v. of Labbé</td>
<td>Altered trajectory of tentorial opening during pst petrosal approach</td>
</tr>
<tr>
<td>8</td>
<td>53, F</td>
<td>Meningioma, ant clinoid</td>
<td>MCA, encased in tumor</td>
<td>Exposure of petrous carotid during cranio-orbital-zygomatic approach for proximal control prior to dural opening</td>
</tr>
<tr>
<td>9</td>
<td>52, M</td>
<td>Meningioma, cerebello-pontine angle</td>
<td>Tentorial v.</td>
<td>Avoided cutting tentorium</td>
</tr>
<tr>
<td>10</td>
<td>68, M</td>
<td>Meningioma, falxine</td>
<td>Superior sagittal sinus patency</td>
<td>Preservation of sinus during tumor resection</td>
</tr>
<tr>
<td>11</td>
<td>56, F</td>
<td>Meningioma, falxine</td>
<td>Superior sagittal sinus patency</td>
<td>Saphenous v. graft for superior sagittal sinus</td>
</tr>
<tr>
<td>12</td>
<td>62, M</td>
<td>Meningioma, optic nerve sheath</td>
<td>Prominent frontal v.</td>
<td>Limited lat exposure of craniotomy to preserve v.</td>
</tr>
<tr>
<td>13</td>
<td>33, F</td>
<td>Meningioma, petroclival</td>
<td>Tentorial v.</td>
<td>Avoided cutting tentorium</td>
</tr>
<tr>
<td>14</td>
<td>41, M</td>
<td>Meningioma, petroclival</td>
<td>Tentorial v. &amp; v. of Labbé</td>
<td>Altered petrosal approach to retrosigmoid approach to avoid cutting tentorium</td>
</tr>
<tr>
<td>15</td>
<td>51, M</td>
<td>Meningioma, petroclival</td>
<td>Tentorial v. &amp; v. of Labbé</td>
<td>Altered petrosal approach to retrosigmoid approach to avoid cutting tentorium</td>
</tr>
<tr>
<td>16</td>
<td>67, M</td>
<td>Meningioma, petroclival</td>
<td>Tentorial v.</td>
<td>Avoided cutting tentorium</td>
</tr>
<tr>
<td>17</td>
<td>47, M</td>
<td>Meningioma, petroclival/cavernous sinus</td>
<td>Large temporal v. from sylvian fissure to sigmoid sinus, not crossing tentorium</td>
<td>Able to cut tentorium safely</td>
</tr>
<tr>
<td>18</td>
<td>51, F</td>
<td>Meningioma, petrous apex</td>
<td>Sylvian v. crossing tentorium into transverse sinus</td>
<td>Preservation of tentorium during petrosal approach</td>
</tr>
<tr>
<td>19</td>
<td>40, F</td>
<td>Meningioma, petrous apex</td>
<td>Tentorial v.</td>
<td>Altered petrosal approach to retrosigmoid approach to avoid cutting tentorium</td>
</tr>
<tr>
<td>20</td>
<td>48, M</td>
<td>Meningioma, sphenoïd wing</td>
<td>Compressed middle sylvian v.</td>
<td>Identification of proximal vascular control during cranio-orbital-zygomatic approach</td>
</tr>
<tr>
<td>21</td>
<td>66, F</td>
<td>Meningioma, tentorial/posterior fossa</td>
<td>Large sphenoparietal sinus</td>
<td>Avoided overly ant temporal flap</td>
</tr>
<tr>
<td>22</td>
<td>46, F</td>
<td>Meningioma, tuberculum sella</td>
<td>Prominent frontal vein</td>
<td>Limited lat exposure of craniotomy to preserve v.</td>
</tr>
<tr>
<td>23</td>
<td>48, M</td>
<td>Paraganglioma, glomus</td>
<td>ICA occlusion</td>
<td>Ability to sacrifice carotid artery</td>
</tr>
<tr>
<td>24</td>
<td>39, M</td>
<td>Schwannoma, hypoglossal</td>
<td>Compressed but patent IJV</td>
<td>Management of IJV during transcondylar approach</td>
</tr>
<tr>
<td>25</td>
<td>37, M</td>
<td>Schwannoma, jugular foramen</td>
<td>PICA, encased in tumor</td>
<td>Initial exposure of tumor w/ search of PICA origin</td>
</tr>
</tbody>
</table>

*ant = anterior; ICA = internal carotid artery; IJV = internal jugular vein; lat = lateral; PICA = posterior inferior cerebellar artery; pst = posterior; v. = vein.*
standard CTA, the delivered dose is the sum of the doses associated with the scout image, the noncontrast acquisition, the arterial phase, and the delayed phase (Fig. 1B). In dynamic CTA, the radiation dose is aggregated from the scout image, the noncontrast helical acquisition, and the dynamic vascular imaging (Fig. 1A). As expected, because of a distinct venous acquisition phase, the dynamic CTA/CTV technique imparts a slightly higher effective dose than does standard CTA, in exchange for improved accuracy in venous detection. Standard CTA presents a single snapshot in time, frequently with considerable variation in the phase of contrast transit during which it is acquired, and may result in arterial contamination of venous data or vice versa. In comparison, dynamic techniques capture information from a volume of tissue over time, eliminating the variability of phase acquisition by displaying the entire vascular transit of contrast material to permit isolation of venous from arterial structures for subsequent critical surgical planning.

It is important to remember that dynamic CTA is a relatively new technique, with constant modification of scanning protocols to optimize the dose delivered to the patient for specific imaging applications. For example, in standard CTA, the noncontrast or delayed-venous-phase acquisition can be omitted if it is not needed, to decrease the radiation dose. In dynamic CTA/CTV, the corollary would be to increase the time between “pulses” in the venous or any other phase of the acquisition, as needed (Fig. 1C). This is analogous to the concept of film rate in catheter angiography, in which the dose delivered to the patient can be lowered by decreasing the film rate. Remember that these changes in the scanning protocol, while decreasing the radiation dose, will also affect image quality. In the example of increasing the time between pulses in the venous phase, the scan protocol sacrifices temporal resolution in the venous phase to achieve dose savings.

Another alternative to dynamic CTA/CTV is catheter angiography. However, this remains an invasive procedure.

### TABLE 4. Dose information by imaging modality

<table>
<thead>
<tr>
<th>Modality</th>
<th>CTDIvol (mGy)</th>
<th>DLP (mGy-cm)</th>
<th>Effective Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic CTA</td>
<td>268.3</td>
<td>4409</td>
<td>10.14</td>
</tr>
<tr>
<td>Standard CTA</td>
<td>180.7</td>
<td>2414</td>
<td>5.55</td>
</tr>
<tr>
<td>Catheter angiography</td>
<td>NA</td>
<td>NA</td>
<td>~5</td>
</tr>
</tbody>
</table>

NA = not applicable.
with the attendant risks of thromboembolic complications, procedural sedation, and varying radiation exposure depending on the extent of the external and internal cerebral circulation injections necessary to define the skull base tumor. In addition to patient exposure, the scatter dose delivered to the operator during catheter angiography confers additional overall risk. We propose that dynamic CTA/CTV offers an optimal balance of technical reliability, patient safety, and operator convenience to incorporate into routine use during skull base tumor surgery and into image guidance systems.

Conclusions

Dynamic CTA/CTV offers unique advantages when applied to neurosurgical pathologies and procedures. This noninvasive technology demonstrates all vascular phases and vascular flow patterns, minimizes dependence on contrast bolus timing and false interpretation of early draining vessels, provides high fidelity in detecting circle of Willis arteries and major draining sinuses at a higher sensitivity than MRA/MRV and with a lower risk than catheter-based angiography, and can be integrated into intraoperative navigation systems. We illustrate the clinical impact of dynamic CTA/CTV on routine surgical planning for skull base lesions and propose its use as an important addition to preoperative planning for all complex intracranial tumors.

References


Author Contributions

Conception and design: Dunn, Bi, Al-Mefty. Acquisition of data: Bi, Brown, Abolfotoh, Mukundan. Analysis and interpretation of data: all authors. Drafting the article: Dunn, Bi, Brown. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Dunn. Statistical analysis: Bi. Administrative/technical/material support: Dunn. Study supervision: Dunn.

Supplemental Information

Videos


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